Evaluation of ice formation in large-eddy simulations of Arctic stratocumulus using lidar & radar

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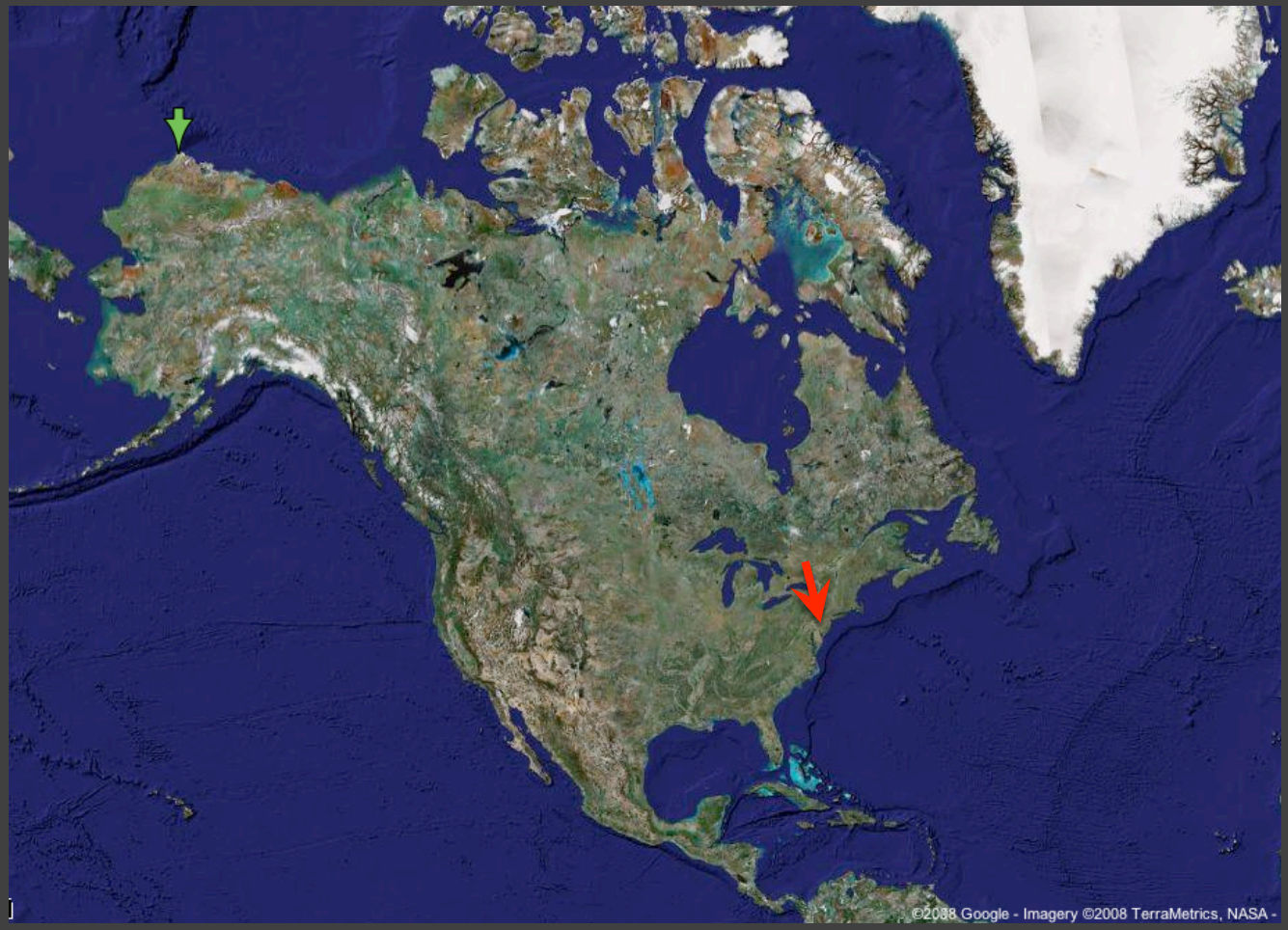
Outline

- Measured and modeled ice in Arctic stratocumulus during M-PACE
- MMCR radar and AHSRL lidar measurements
- Brief description of DHARMA CRM simulations
- Direct comparison of measured and simulated radar and lidar measurements
- Simulations based on aircraft measurements
- Conclusions

M-PACE Measurements at Barrow, Alaska, October 9th/10th, 2004



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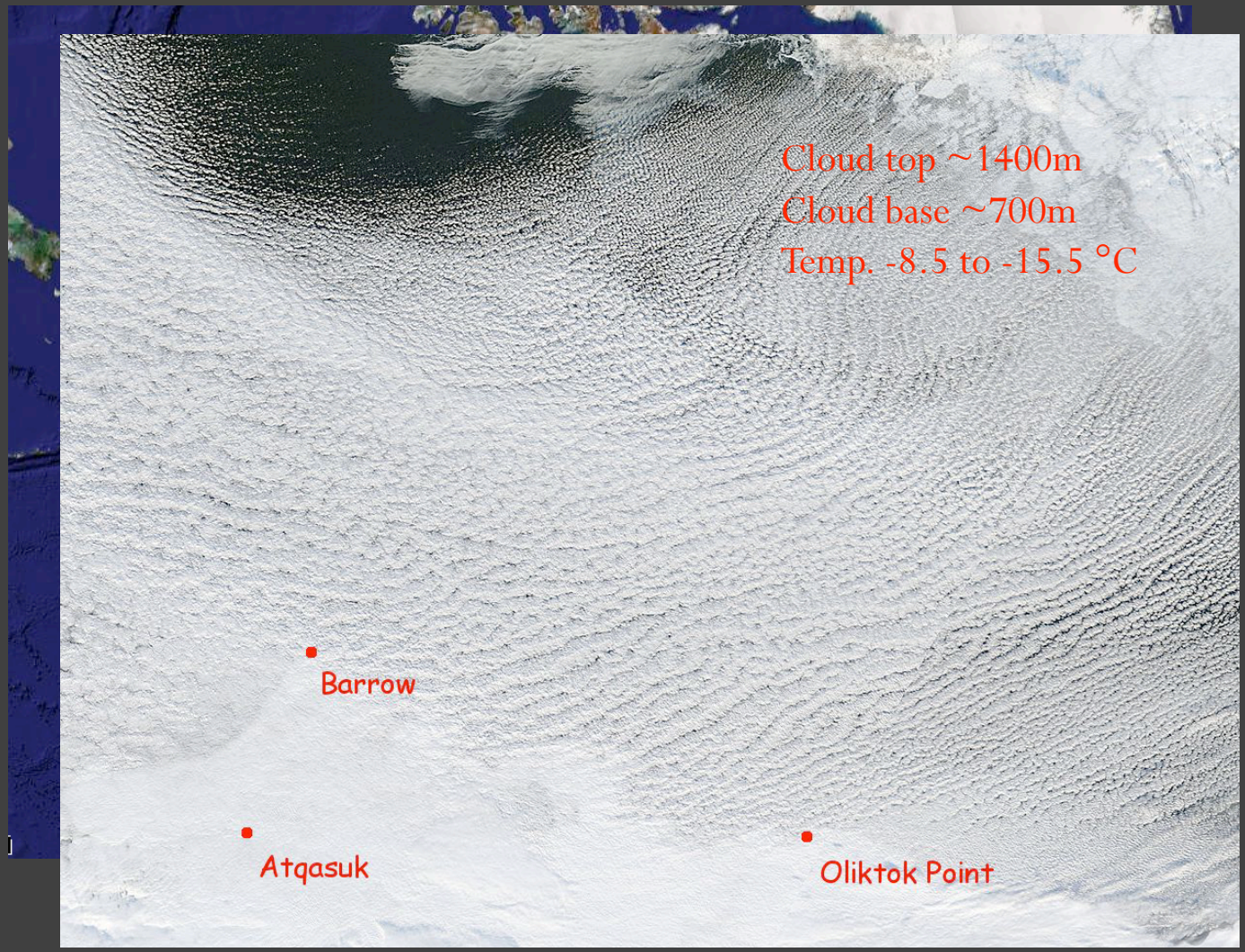
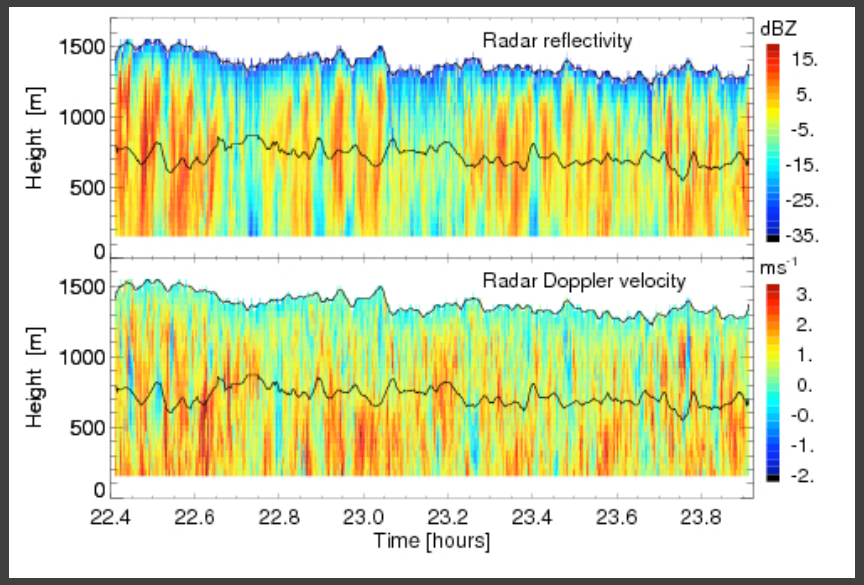


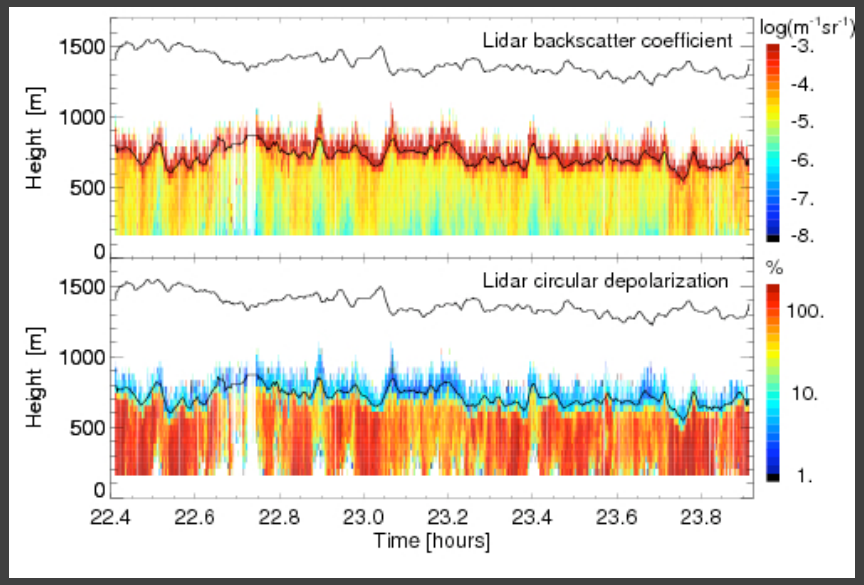
Ice in Arctic stratocumulus

- Aircraft measurements (flight 10a):
  - IWP ~ 11.6 g/m^2
  - IN ~ 0.2 L^{-1} (detection limit)
- CRM results (Fridlind et al. 2007)
  - Using known heterogeneous ice formation and multiplication processes: IWP ~0.03 g/m2
  - Alternative ice formation processes needed for agreement between CRM and measurements
- However, some uncertainties in aircraft measurements (sampling, ice shattering on measurement device)

MMCR Radar and AHSRL Lidar measurements (9 October 2004)



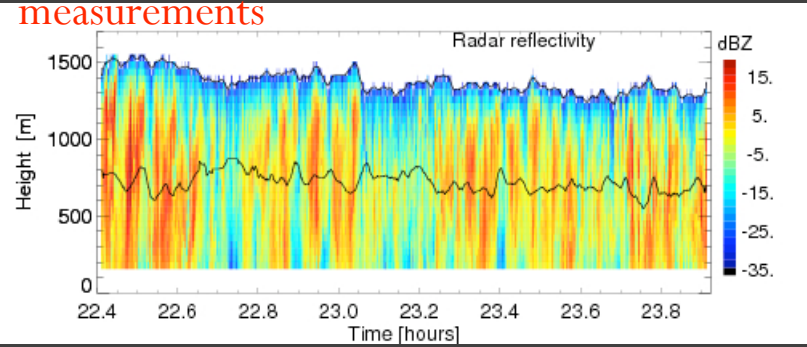
MMCR cloud radar (35 GHz)



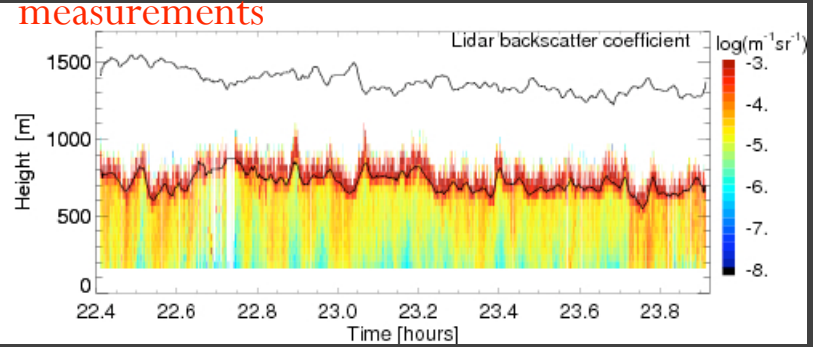
AHSRL lidar

Direct comparison of lidar & radar measurements and CRM simulations

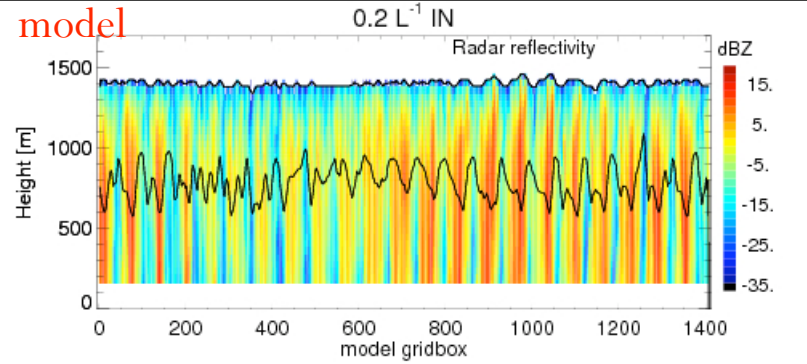
measurements



measurements



model



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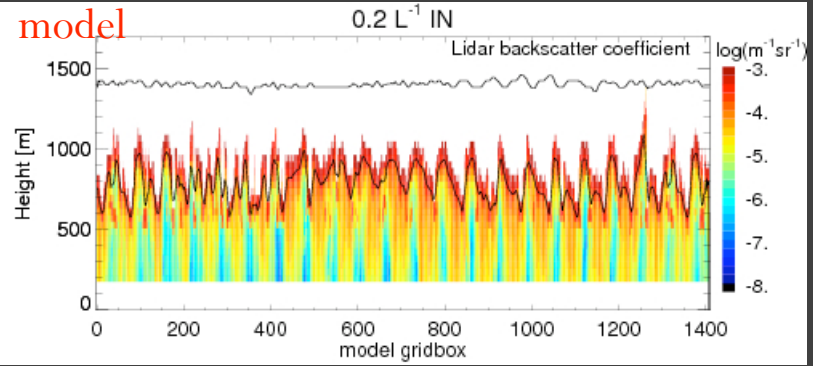


Radar simulations using Quickbeam (Haynes 2007) assuming Mie

Lidar simulations using Mie (liquid) and Geometric optics (ice) assuming irregular columns

Simulations

- DHARMA model (Ackerman et al., 2000)
  - Large eddy simulation model
  - 50 m horizontal, 20 m vertical resolution
  - Size resolved microphysics:
    - 20 size bins each for ice and liquid

Simulations (Fridlind et al. 2007)

a) Base case with background 0.2 L^{-1} IN concentration

To increase ice to measured levels:

b) Slower ice fall speeds and high fragmentation

c) 200 L^{-1} IN concentration

d) Constant surface source of IN (6 L^{-1} in first 100 m)

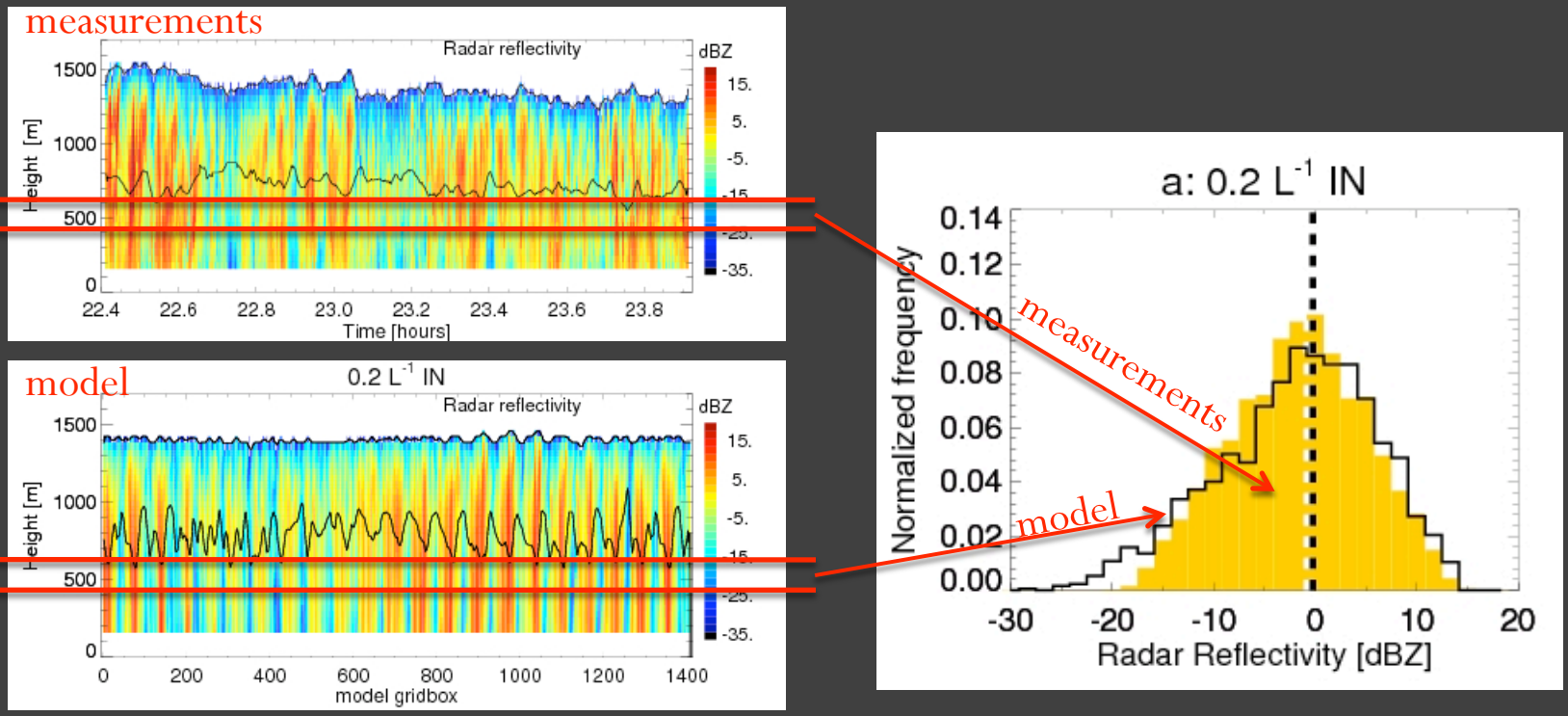
e) Evaporation IN: one in $5x10^5$ drops residuals form IN (e.g. Beard 1992)

f) Evaporation freezing: one in 10^4–10^5 drops freeze while evaporating (e.g. Cotton and Field 2002)

g) Tuned freezing rate per volume (10 $cm^{-3}s^{-1}$)

h) Tuned freezing rate per surface area (0.004 $cm^{-2}s^{-1}$)

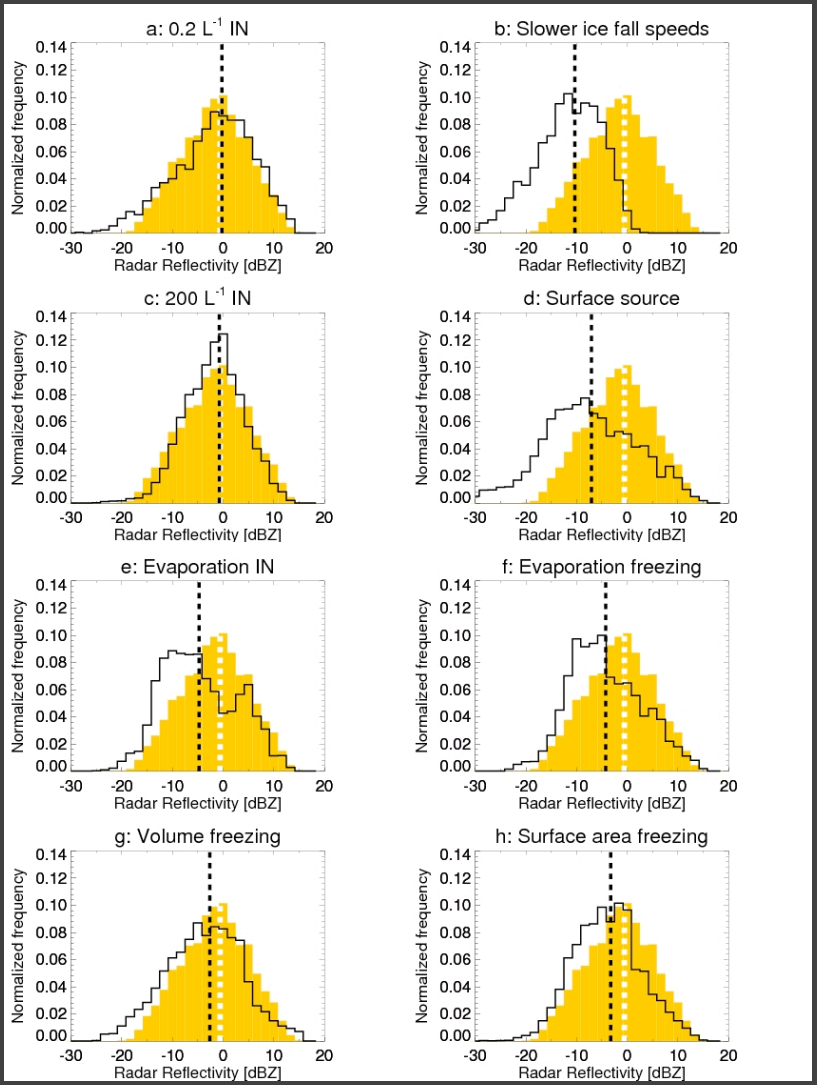
Histograms under cloud base



- Distribution of values between 400 m and 600 m altitude
- Sampled 3 model fields after 11h00m, 11h30m and 12h00m simulation time

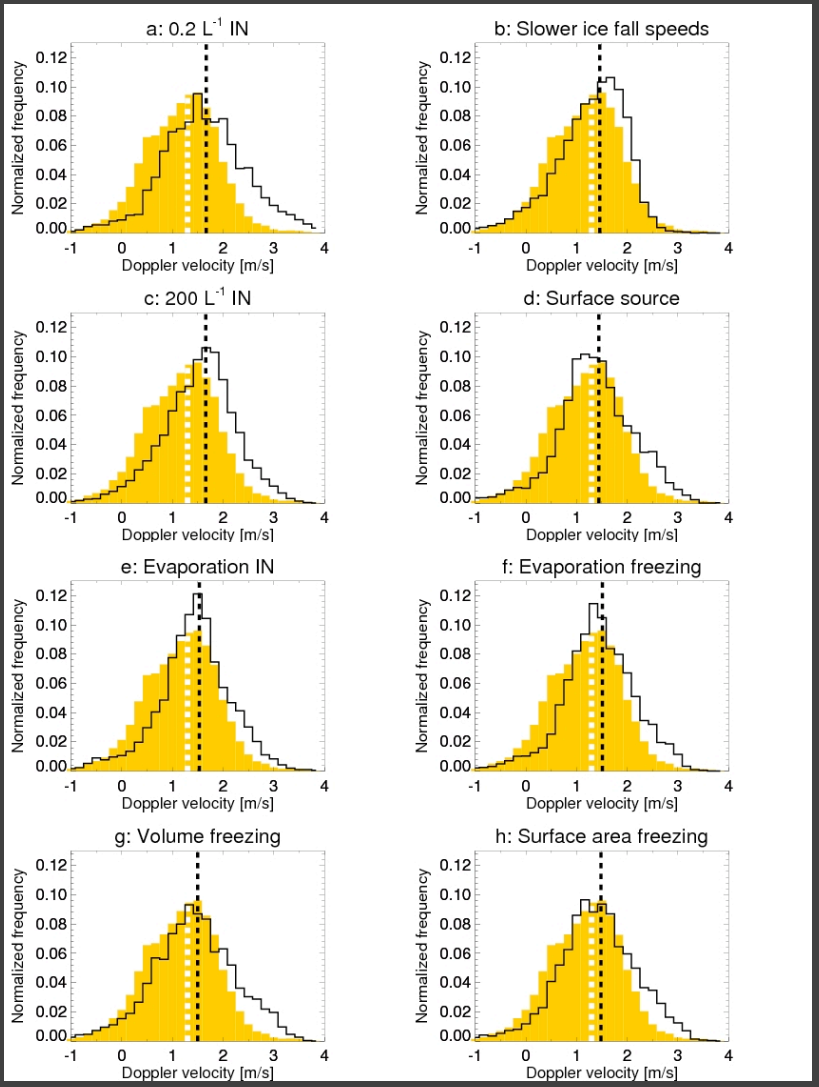
Radar Reflectivity under cloud base

- Fairly good agreement with measurements for all but
  - Slower ice fall speeds
  - Surface source



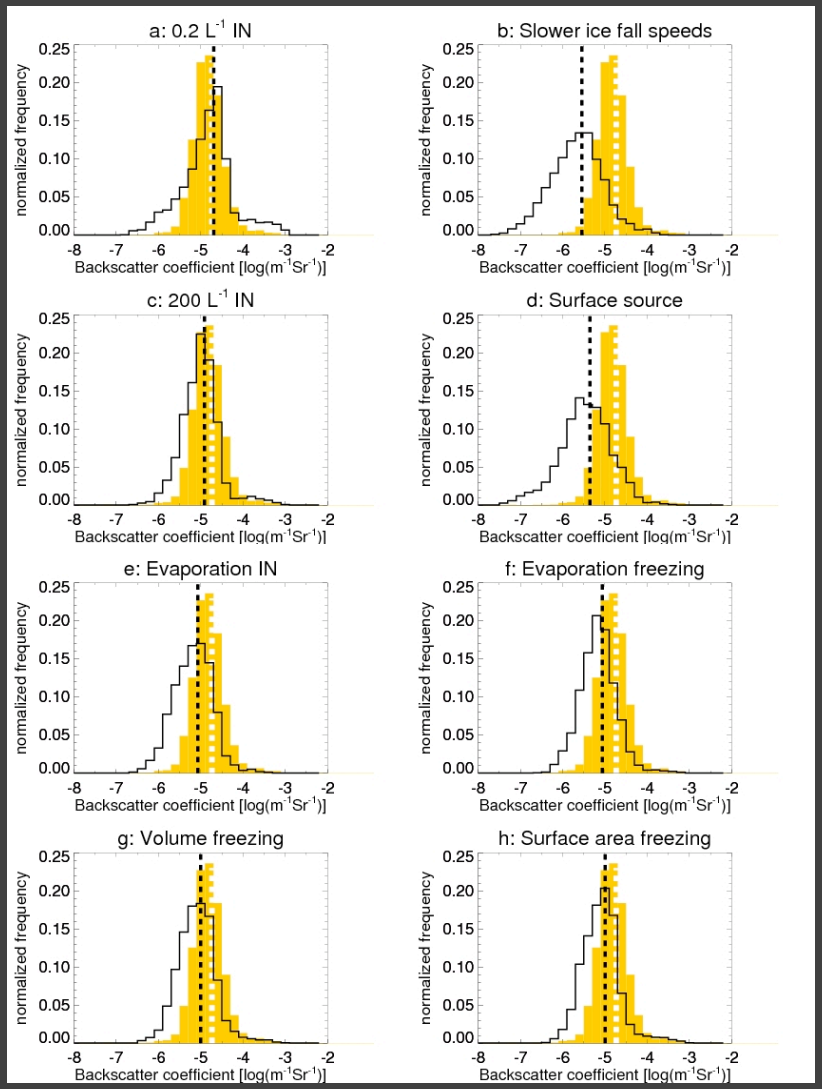
Radar Doppler velocity

- Good agreement with measurements
- All cases exhibit bias positive bias ~0.2 m/s



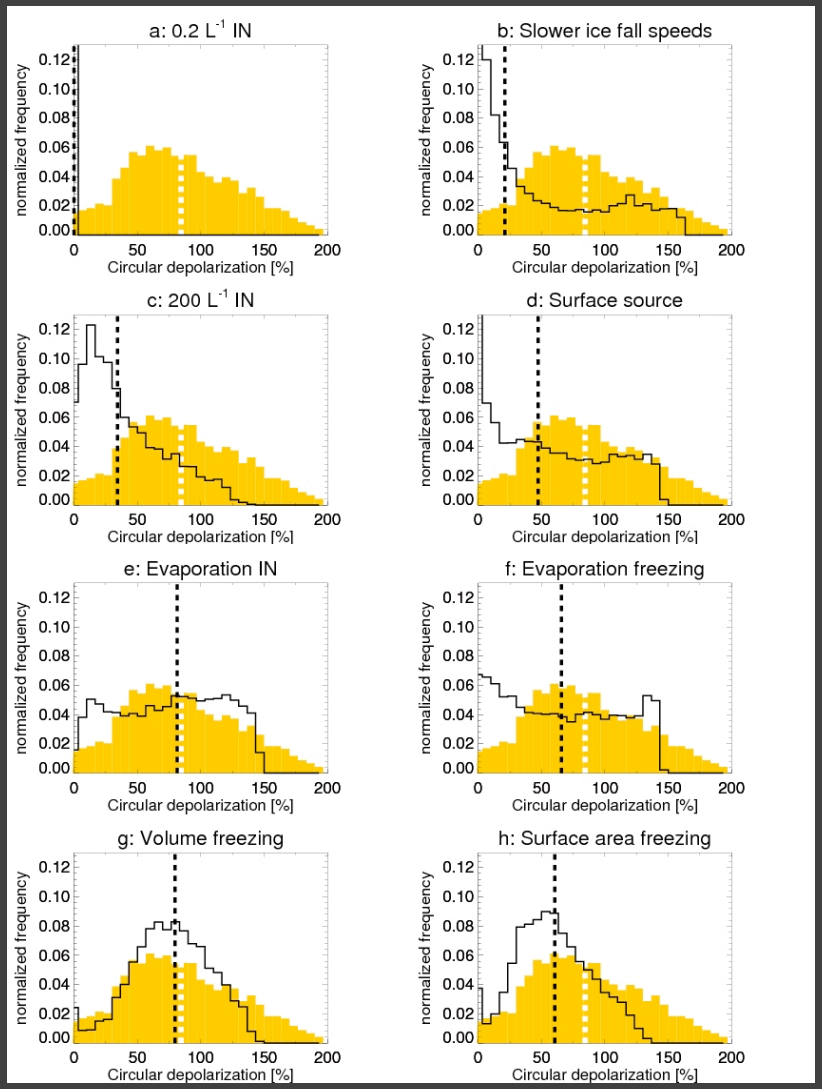
Lidar Backscatter coefficient

- Again fairly good agreement with measurements for all but
  - Slower ice fall speeds
  - Surface source
- Most other cases exhibit negative bias of about 0.3 log(m^{-1} Sr^{-1})

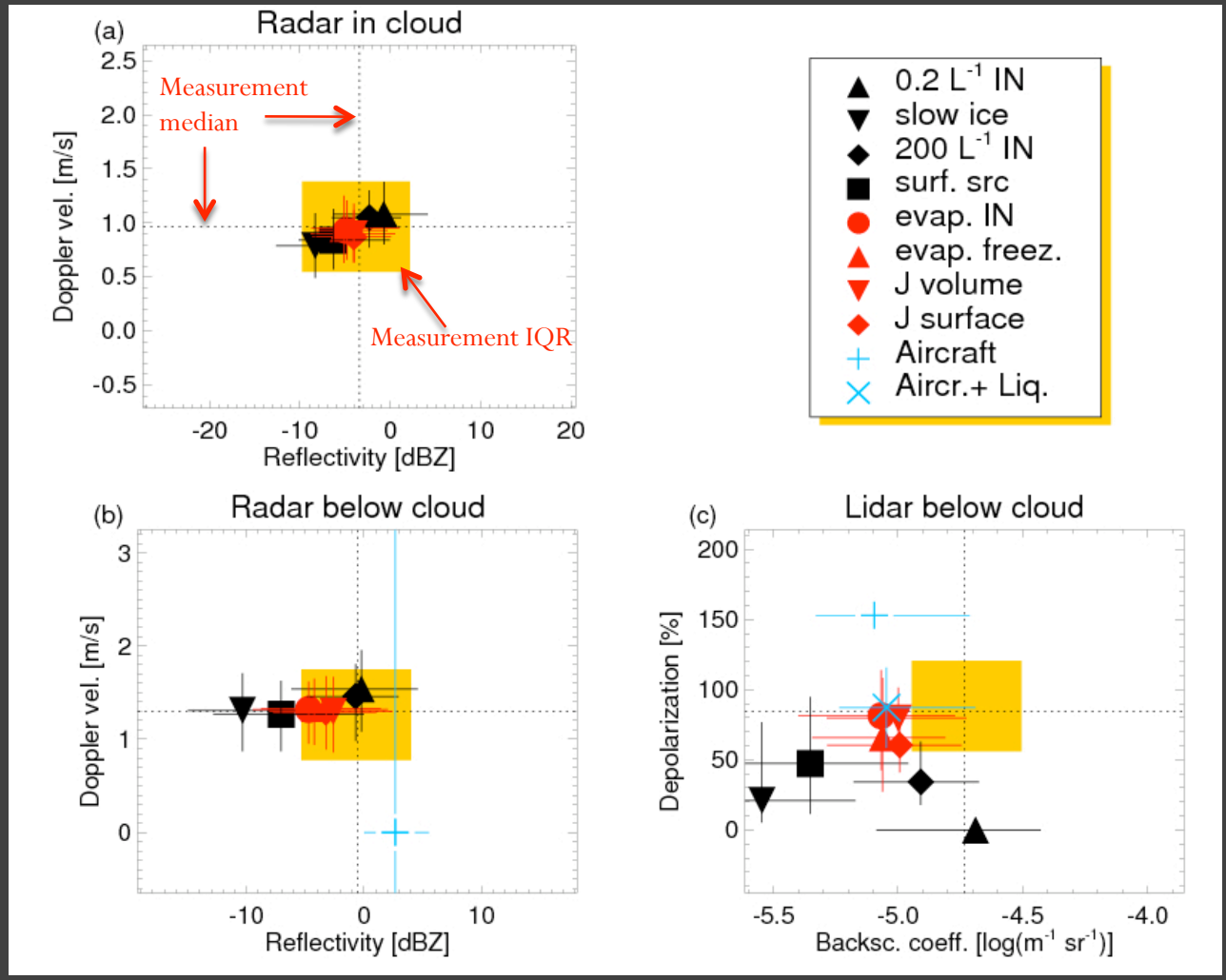


Lidar circular depolarization

- Only good agreement for
  - Evaporation IN
  - Evaporation freezing
  - Volume freezing
  - Surface area freezing



Overview:
medians (symbols) and IQRs (bars)



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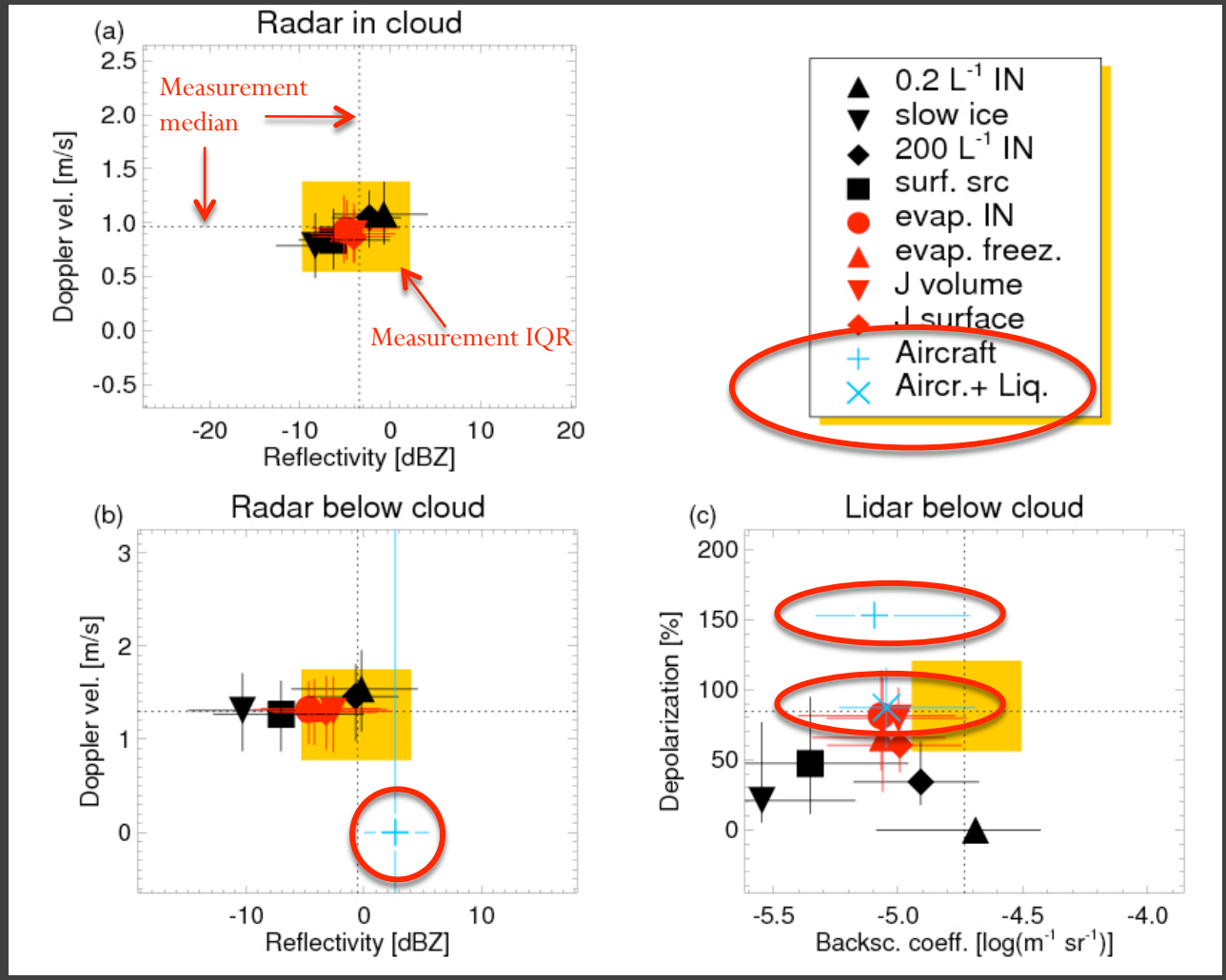
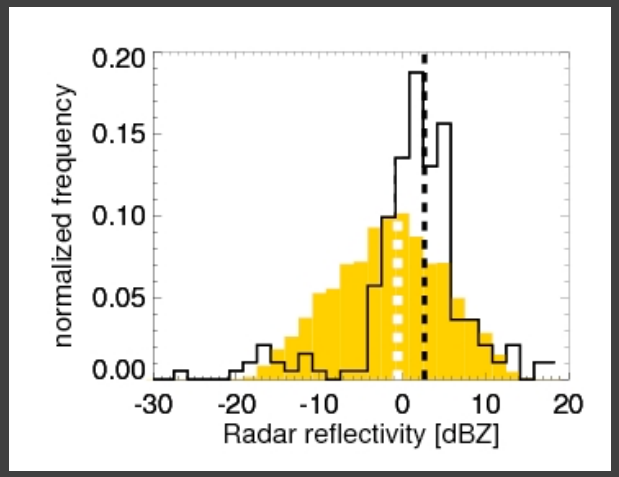
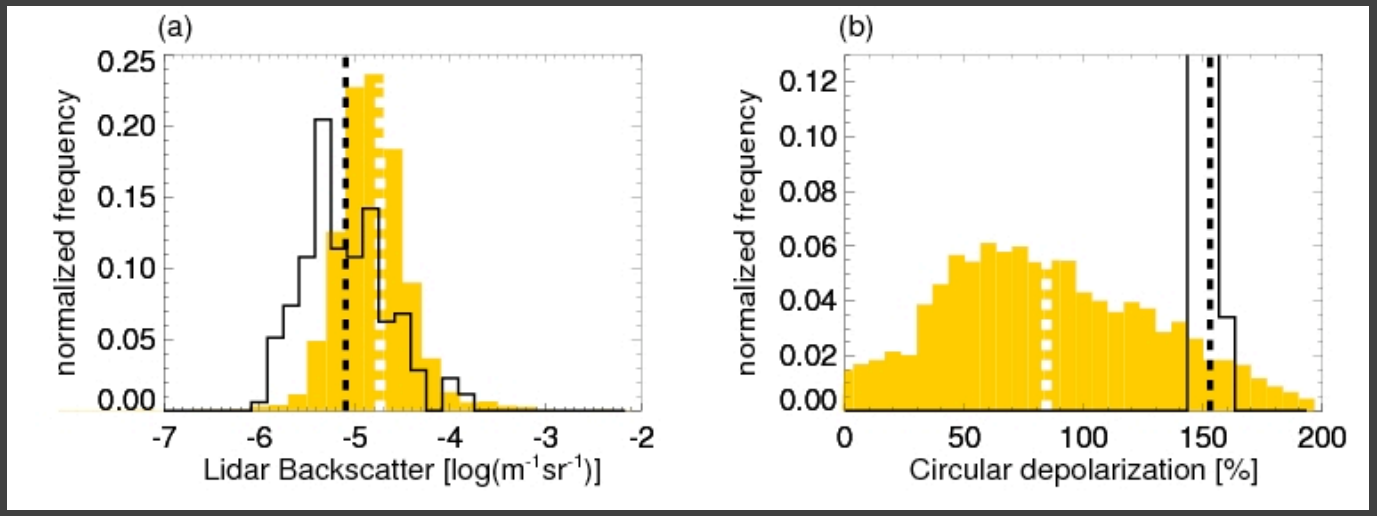


Simulations based on in situ aircraft measurements

- FSSP, 2DC, HVPS; (McFarquhar et al. 2007)
- Assuming all particles under cloud are ice





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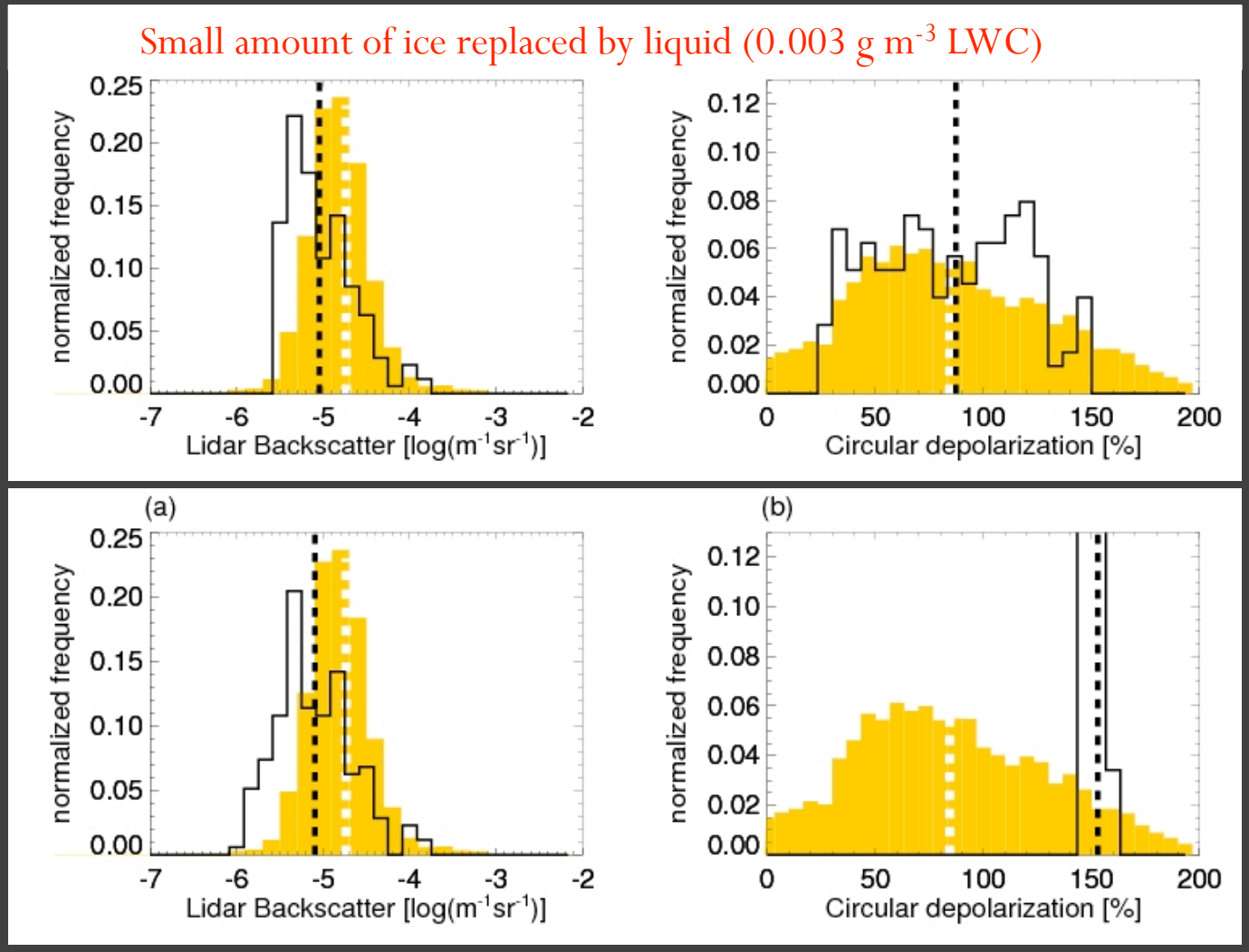

Summary and conclusions

- Direct comparison of radar and lidar measurements to CRM simulated values:
  - Radar reflectivity identifies biases in large ice/drops
  - Radar Doppler velocities suggest modeled fall speeds are realistic
  - Lidar backscatter identifies biases in weighted cross sections under cloud base
  - Lidar depolarization identifies biases in relative amounts of ice/liquid under cloud base
- Adds additional independent evidence for unestablished ice formation processes in Arctic stratocumulus
- Lidar depolarization distribution primarily determined by relative amount of ice/liquid


Thank you
Picture taken while preparing for talk